Residential Energy Consumption and Evaluations of Energy Saving Strategies in China

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論 文 内 容 要 旨

1. Introduction

In recent years, a great deal of attention is paid for environmental issues on a global scale, and efforts to reduce greenhouse gases such as carbon dioxide, and the promotion of energy conservation has been a countermeasure for global warming and air pollution. The developed countries have implemented various policies and measures for energy saving. Developing countries have lagged behind developed countries in residential sector, and there is a large energy saving potential. Thus, current situation and future trends in residential energy use and influence factors on energy use in developing countries is necessary to reveal.

The rapid economic expansion in China has propelled it to the rank of the largest energy consuming nation in the world, with energy demand growth continuing at a pace commensurate with its economic growth. Especially for residential sector, the energy consumption increased 102% from 1990 to 2008. This rapid increase of energy consumption leads to serious environment problems such as global warming, air pollution and acid rain.

Along with the increase of economy and population, and the acceleration of industrialization and urbanization, the energy consumption in China became second largest consumer after USA in the world. In order to achieve a good balance among energy consumption, natural environment and economic development, it is vital to know the actual situation of energy use and its influence factors, this information enable us to estimate the future trend of residential energy consumption, as well as the possibilities and the strategies for energy saving in China.

By analyzing the existing researches, it is found that the samples of analysis in the research do not cover five climate zones, hence detailed analysis of the data collected to influence factors, characters of buildings, families and housing appliances is lacking. In addition, some researches focused on the use of one energy resource such as electricity, or one end use of air-conditioners, or energy use in one season (summer or winter). Moreover, the influential factors to the energy consumption were not clearly analyzed. Thus, the characteristics of energy consumption cannot be comprehensively revealed, the items of

analysis are also too limited to conduct further detailed analysis. For the above mentioned reason, a research is deemed to be necessary in order to obtain meaningful as well as useful results for preparing programs to minimize energy in China. This research not only analyzed the annual energy consumption characteristics in residential sector, but also revealed the correlated influence factors on energy use and evaluated the effect of energy saving strategies. This study aims to understand residential annual energy use characteristics and their influence factors of each climate zone in China, and effect of energy policy and energy saving strategies. The data of questionnaire survey in Kunming is done by author. The data of questionnaire in other cities are from database in Sustainable Environment Creative Laboratory, Graduate School of Engineering, Tohoku University, but it was re-processed by author referring the method in other research [1] in order to get valid data for the further analysis.

2. Questionnaire survey on energy consumption

The questionnaire surveys on energy consumptions are carried out in residential buildings distributed in each climate zones of China (questionnaires are distributed to 1276 families in thirteen cities in summer and winter seasons), with the purpose to get the actual characteristics of buildings, household appliances, and total annual energy consumption in residential buildings. In addition, the changes in ten years in six cities are analyzed, and the existing policy for space heating in very cold and cold zone is discussed.

The investigated households have divided into two groups, namely Group 1 with districting heating in northern China and Group 2 without district heating in Southern China. The annual energy consumption in Chongqing reaches 19.2GJ which is the largest among the households in Group 2, in which cooking accounts for 7.1 GJ per household. Guangzhou is the fourth largest energy consumer which reaches 15.2 GJ per household in Group 2, in which cooking accounts for 7.2 GJ. It can be seen that the energy consumptions of cooking in Guangzhou and Chongqing are the first and second largest part in total energy use.

The questionnaire survey revealed that each household with district heating operated heating in 24 hours, everyday in winter even occupants did not stay at home. By estimation based on another research [2], it is found that Beijing(A) with district heating used 51.4 GJ per household for space heating which is the largest part in the total energy consumption, while in Beijing(B) without district heating used 3.1 GJ per household. There is a big potential to save energy for district heating considering the fact that thermal insulation is no enough and windows are opened when the indoor temperature is going to rise.

3. Analysis of influence factors on annual energy consumption

The influential factors on energy consumptions in residential buildings such as floor area, building age, building structure, window frame family size, etc are analyzed with statistical methods based on the results of questionnaire and energy consumption from chapter 2.

In northern China with district heating, the influence factor analyses show that the investigated buildings built after the 90s

are distinctly more energy efficiency than before 90s. One of the reasons is that the Department of Construction of PRC issued a revised national enforcement standard "Energy conservation design standard for new heating residential buildings", JCJ 26-95 in 1995 and a national enforcement standard "Thermal design code for civil building", GB 50176-93 in 1993 respectively. Thus, the buildings built before 90s need retrofit using these new standard for energy saving.

The type of water heater is an important factor that influences annual energy consumption in investigated ten cities. Solar energy water heater helps to save energy. The households equipped with solar water heater used less energy than others, however, only 13% and 18% households in Group 1 and Group 2 installed it respectively, especially in Dalian, only 2% households owned it. Thus, making corresponding policy to increase its possession rate is necessary for energy saving.

The households with higher annual income used more energy. It can be considered that the current policy of energy price needs to change from same rate to different rate: when energy use exceeds average value, the energy use is larger and price is higher.

The larger floor area, number of family members, annual income and iron window frame are main reasons resulting in the more energy consumption in Chongqing, Nanjing and Beijing. The small family size, lower annual income, small floor area and plastic steel window frame are the main reason resulting in the less energy consumption in Kunming, Maanshan and Shanghai.

In Chapter 2 and Chapter 3, only basic information of residential buildings are analyzed, however, there are some other considerable factors such building envelops, building equipment and the behaviors of occupants should be taken into account. For this reason, more detailed field surveys and analyses were carried out and analyzed in the next chapter.

4. Field measurement on energy consumption

The field measurement on energy consumptions by different end-users and thermal comfort were carried out in residential buildings in each climate zones of China. The characteristics of each end use in a year, different seasons and in the hottest/coldest days, and the differences between the households with district heating and the households with domestic heating were analyzed.

There is a big difference (29.5 GJ/year between maximum and minimum) on energy use between houses due to different household equipment used and different occupant behavior of energy consumption. While no significant changes of energy use for lighting, and audio visual & information are found among four seasons.

House 08 in Beijing used 32.4 GJ in a year (heating reached 18.5 GJ, accounting for 57% of the total consumption), which is the largest in Group 2 without district heating since the full house is heated by home central gas heating system. House 09 in Shanghai used 31.6 GJ (heating shared only 2 GJ) has many housing equipment and wasted energy. The cooking consumption is the largest part in Group 1 and second largest part in Group 2. Relating indoor environment, a big difference of average

indoor temperature is found in the coldest days between Group 1 and Group 2 (Group 1: 20 ℃, Group 2: 10 ℃).

5. Evaluations on energy saving strategies by numerical simulations

The numerical simulations are carried out using one of apartment units in Chapter 4 as a model, so as to evaluate the impacts of energy-saving techniques and occupant behavior related to energy consumption.

Thermal insulation and air tightness are effective ways, to peruse energy conservation for space heating. If apartment units in northern region are thermally insulated and sealed, energy consumption for residential buildings will be significantly reduced.

Occupant behavior is an important influence factor on energy consumption. The heating will deduce 11% when temperature was changed from 20°C to 18°C and cooling will deduce 20% when cooling temperature was changed from 26°C to 28°C.

6. Conclusions

(1) Based on the analysis on 1276 questionnaires and field measurement in 12 houses, this research is the first time, which not only get the annual energy use characteristics nationwide, but also reveal the related influence factors on annual energy consumption clearly, and get the detailed information for each end use of energy consumption, and some proposal to improve energy policy

(2) The investigated buildings built after the 90s are distinctly more energy efficiency than before 90s, and the type of water heater is an important factor that influences annual energy consumption in investigated ten cities.

(3) There is a big difference on energy use between houses due to different household equipment used and different occupant behavior of energy use. However, there are no significant changes of Lighting, and Audio visual & information among four seasons.

(4) If apartment units in northern region are thermally insulated and sealed, energy consumption for residential buildings will be significantly reduced. Making occupants have better behavior on heating, cooling, cooking and hot water is a cheap and useful method for energy saving.

(5) It can be considered that the current policy of energy price needs to change from same rate to different rate: when energy use exceeds average value, the energy use is larger and price is higher.

7. References

[1] Chen, S.; Yoshino, H.; Li, N. Statistical analyses on summer energy consumption characteristics of residential buildings in some cities of China. Energy and Building 2010, 42, 136-146.

[2] Yu, L.; Watanabe, T.; Yoshino, H.; Gao, W. Research on energy consumption of urban apartment buildings in China. J. Environ. Eng. 2008, 73, 183–190.

論文審査結果の要旨

中国の様々な気候条件にある10都市の約1300の住宅を対象としたアンケート調査結果と、6都市12戸における詳細なエネルギー消費量と室内環境の測定データを使って、統計的分析、事例的分析、数値解析によって、エネルギー消費量と関連要因との関係を明らかにし、エネルギー消費を節約する上での手法とその効果について示した論文である。

第1章は序論であり、中国のエネルギー消費の状況、既往の研究、論文の構成について述べている。

第2章は、アンケート調査で得られたエネルギー消費量や関連要因に関するデータの分析結果である。地域暖房が利用されていない住宅では、年間のエネルギー消費量は 12.2～19.2GJ であり、暖房用の割合は寒冷気候にある北京では20%であるが、それ以外では7%以下と少ないこと、調理用が30～40％を占めること、また日本の平均の1/4～1/2、米国の1/5程度であることなどの特徴を明らかにしている。また、地域暖房が利用されている住宅の暖房用エネルギー消費量については既往の文献から推定しており、北京の場合では全体のエネルギー消費量が64GJ であり、暖房用が80%を占めることを示している。この値は、全室暖房を行っている北海道の住宅の平均値よりも多く、中国の集合住宅では断熱材が十分には設置されていないこと、室温が高い場合には居住者が窓を開けて温度を下げていることなどを考慮すると、暖房消費量を削減できる余地があることを述べている。

第3章は、2章と同じデータを用いて統計的な分析を行った結果である。数量化Ⅰ類を用いたい分析では、地域暖房が利用されていない地域での分析結果によれば、建設年数が古いほど、床面積が広いほど、収入が多いほど、家族人数が多いほど、年間のエネルギー消費量が多いことを明らかにしている。また、数量化Ⅲ類を用いた分析では、都市によってエネルギー消費や影響要因に明確な差が表れており、例えば重慶はエネルギー消費量が多いが、床面積が大きい、家族人数が多い、収入が多いことなどと関係があり、昆明はエネルギー消費量が小さいが、床面積が狭く太陽熱集熱器の普及率が高いことなどと関連していることを述べている。これらの統計的な分析結果は、この論文で初めて明らかにしており重要な知見である。

第4章は、各都市の12戸を対象としたエネルギー消費量と室内環境の1年間にわたる詳細調査の分析結果である。地域暖房の使用されていない住宅における年間エネルギー消費量は 13～32GJ と大きく異なり、消費量の多い北京の住宅では暖房用が 55%を占めていること、同様に消費量の多い上海の住宅では暖房用は 16%と少ないが、各種の家電製品が贅沢に使われていること、また、地域暖房の設置された住宅では、暖房消費量は含まれていないが3～17GJ とばらつき、極めて消費量の少ない住宅も見られた。住まい方の違いによってエネルギー消費量も大幅に異なり、省エネルギーの方策を検討する上では貴重な資料が得られている。

第5章は、調査で対象となった北京の住宅を計算モデルとして、省エネルギーのための対策、断熱材の設置、換気量の削減、設定温度の変更などの効果を数値計算で明らかにしている。

以上、要するに大規模なアンケート調査結果と詳細な測定結果に基づいて、中国の都市住宅におけるエネルギー消費実態と影響要因の関係を明らかにするとともに、数値計算によって対策の効果を定量的に示しており、建築環境工学に対する貢献が大きい。

よって、本論文は博士(工学)の学位論文として合格と認める。